REVIEW OF PESTICIDE APPLICATION RESEARCH IN OHIO AND THE U.S.

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ABSTRACT

This review of pesticide application research will be discussed in two sections. First, a summary of research in the U.S. will be given, followed by a discussion of research in Ohio. There are several universities, federal laboratories and industrial locations in the U.S. where research on pesticide application is being conducted. We will review only selected research projects here, mostly related to spray drift, precision farming, whitefly control, and bio-control methods. The major effort on application technology research in Ohio is conducted in three research units. All authors are associated with the Laboratory for Pest Control Application Technology (LPCAT) with at least adjunct appointments, and work cooperatively on many projects. For discussion purposes, projects will be divided into three groups, based on the major source of funding. The groups are: LPCAT, FABE Department, and USDA-ARS, ATRU. Research projects now active and/or active in the recent past are discussed. Approximately 30 research projects in Ohio are summarized and published references listed.

INTRODUCTION

Research programs in the U.S. have a tendency to follow trends, i.e., certain research areas become popular and many scientists conduct research programs in this area. Currently there is much interest in precision farming. This leads to several research topics in pesticide application. In precision farming, it is useful to control the sprayer output, and to change spray application rates from on part of the field to another. Therefore many research projects are aimed at this problem, for example, in-line injection, on-off flow controllers, weed/crop sensing, etc. Drift of pesticide is another popular area of research. Many studies are being conducted on low drift nozzles, drift retardant adjuvants, and drift modeling. Sometimes grower problems trigger research effort. A few years ago some species of sweet potato white fly developed a resistance to the commonly used pesticide. This insect caused much damage to many crops

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throughout the southern and western U.S., and many research projects were initiated to control this pest. Whiteflies tend to live on the bottom of leaves at the bottom part of the canopy; research was conducted on canopy penetration and spray deposit patterns on the bottom of leaves. Using reduced rates of pesticide is a continuing research goal, so many studies on deposit and spray technology to improve deposit uniformity is conducted on many crops in all parts of the U.S.

SUMMARY OF RESEARCH PROJECTS

IN THE U.S., EXCEPT OHIO

Precision farming:

In addition to studies in Ohio, several other groups are conducting research related to precision farming. We have included some IPM/ICM techniques in this section because precision farming inherently integrates many IPM/ICM practices in a controlled way. Systems for in-line injection of pesticide usually include controls that are useful for controlling the application rate of sprayers. Tompkins et al.(1990), Rockwell and Ayers (1996), Qui et al. (1998) have studied the problems associated with inline injection. Giles and Ben-Salem (1992) and Giles (1997) developed a solenoid-controlled nozzle for adjusting flow rate over a wider range than is possible with pressure changes, without changing the spray pattern or droplet size. This spray system is now being commercially manufactured in the U.S. This system can also be used to spray larger droplet sizes by operating larger nozzles with more 'off-time'. Vetter (1995, 1996) tested the effectiveness of GDPS for guidance of ground and aerial spraying. Chaisattapagon and Zhang (1991), Franz et al. (1995), Simonton and Graham (1996) and others have attempted to identify plant types by using image analysis. Such a system would allow more precise control of herbicide sprays. . Giles and Slaughter (1997) used an imaging system to control the width of a spray band used for spraying a row of small plants. Meyer et al. (1998) developed a system to identify plants from soil and to discriminate among several weeds. Ngouajio et al. (1998) developed a system to estimate the area covered by weed and crop canopies and bare soil. An imaging system captured frames and the image system selected 1000 pixels for classification by an operator. The system was quite accurate in field studies with several types of weeds at several densities but not as accurate with small corn plants.

Some commercial sprayer systems for pre-emerge herbicide application identify plants growing in bare soil by using detectors for reflected light. Some systems are passive, i.e., the light source is ambient light, whereas other systems include a beam of light source of known wavelength and intensity. Hanks (1995) found the sprayer with the light source detected plants more reliably than the passive-detector sprayer, due to soil background changes (wetness, organic matter content, soil type, etc.) and angle and intensity of the sunlight.

Parish et al. (1995) studied the effect of tillage practices for weed control to minimize pesticide use.

Spray drift

The Spray Drift Task Force (SDTF) is a association of 36 agricultural chemical

manufacturers who combined their efforts to plan and conduct drift measurements from spraying with aircraft (both fixed- and rotary-wing), ground boom, air-blast, and chemigation spray applications. They also conducted extensive measurement of physical properties of a wide range of agricultural spray tank mixtures, measured evaporation of spray droplets, and the droplet size spectrum from a wide range of agricultural nozzles under actual field conditions (simulated wind and travel speeds, etc.) These studies were intended to convince the USEPA that spray drift is controlled by many factors, but that the active ingredient is not an important factor. This means that the companies would not have to conduct drift studies for every chemical. The SDTF and EPA are also developing computer models to predict downwind deposits for each spray system – aerial, ground boom, and air-blast. Many papers and presentations have resulted from this massive effort. A few examples are: Teske et al. (1998), Huddleston et al. (1995), Hewitt et al. (1998)

Bui et al. (1998) report on an on-going study to identify suitable samplers for measuring airborne spray. Several other groups have considered the effect of nozzle type on swath deposit (Smith (1992).

Whitefly control

Coates (1996) and Coates and Palumbo (1997) tested several sprayer treatments for control of whitefly in cotton and cantaloupes. They found that air-assisted and electro-static sprayers deposited more spray on the underside of leaves and produced somewhat better control of whitefly in the early season. However, when the canopy was mature, there was no significant difference among sprayer treatments.

Bio-control methods

Delwiche et al. (1998) developed a labor saving method of applying pheromones to orchard trees that released the active ingredient over a longer time period than standard delivery systems. Morisawa and Giles (1995) measured damage to insect larvae exposed to handling techniques required for possible mechanical delivery systems.

SUMMARY OF RESEARCH PROJECTS IN OHIO

The most important element in any research program is the people involved. Therefore we begin the discussion of research in Ohio by listing scientists associated with each major research team.

Laboratory for Pest Control Application Technology (LPCAT)

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Ross D. Brazee, Research Leader, *Robert D. Fox*, Agricultural Engineer, *Richard C. Derksen*, Agricultural Engineer, *Charles A. Krause*, Plant Pathologist, and *Michael Klein*, Entomologist.

LPCAT PROJECTS

Bioavailability

The research focus is on the interaction of application and biological effect. This includes the process whereby an applied toxin is encountered by the target organism, transferred to the target, arrives at the active sight, and produces a biological result. Some parts of this process are unique to individual crop protection agents (e.g. herbicides, insecticides) while other aspects are more universal. For pesticides which are sprayed, the spray must impact and be retained by the target surface (plant or soil). The retained pesticide must be encountered by the target organism. Contact is through movement and feeding for insects. For soil applied herbicides contact is through plant growth. Uptake of pesticide is through a series of events which are affected by plant and insect cuticular microstructure, pesticide formulation and adjuvants, target metabolism, application method, and behavior. Reliable information on the effects of these variables does not exist, and there is no general body of theory to aid in predicting their effects. As a result many of the questions asked in scientific articles 50 years ago are the same ones being asked today. Advances in other fields (mathematics, computer science, chemistry, etc.) continue to provide solutions to intractable problems in understanding this complex process which is fundamental to understanding and manipulating bioavailability. LPCAT as a multidisciplinary team has played a key role in applying these innovations to understanding this process. This work has recently been facilitated through a three year EPA grant for examining the dose transfer process in biopesticides. References: Hall (1991c), Hall et al. (1996a,b) Hall (1997a), Hall (1997), Wolf et al. (1997)

Deposit structure and efficacy

This project has developed the use of mixture models for examining the relationship between deposit structure (deposit size, deposit number and a.i. per deposit) and biological effect. These efforts have included the development of bioassays (cabbage looper on insecticide treated cabbage, and glyphosate treated velvetleaf), and the development of a computer simulation. The computer model allows rapid evaluation of a large number of "experiments" while the bioassays provide a biological foundation. The Pesticide Dose Simulator (PDS) model can be used to explore the effects of deposit structure on efficacy. Mixture design models have led to several non-intuitive insights into the dose transfer process which clear up several inconsistencies in the literature - such as smaller droplets providing better efficacy in the lab, but CDA sprayers (which produce smaller droplets) requiring similar application rates in the field. Basically: 1) the chance of an insect dying from a pesticide application is never less than the probability of contacting the toxin; 2) uniform deposit structures result in lower insecticide efficacy for mobile chewing insects because they do not acquire a large

enough dose rapidly enough for the toxin to overcome insect growth. The former has promoted the notion that uniform applications are "good" while the latter has forced increased application rates to overcome the disadvantage of a uniform application. References: Adams and Hall (1990), Royalty et al. (1990), Adams et al. (1990b,1992), Thacker and Hall (1991), Thacker et al. (1992), Cooper and Hall (1993), Hall et al. (1993b), Head et al. (1995), Downer et al. (1997), Hoy et al. (1998)

Spray Atomization and Patternation

The Aerometrics Phase Doppler Particle Analyzer is being used to obtain droplet size spectra data of pesticide and additives. An Image Analyzer (IA) is used to size pesticide deposits on target surfaces, e.g. water sensitive paper. Water sensitive spray cards which capture droplets and allow for size measurements by the IA are extensively used in the field. A unique spray simulation lab is used to monitor spray patterns and >capture efficiencies of various plant canopies. In the past four years, atomization studies have included: effect of drift retardants on droplet spectra; effect of shearing polymers on spectra; effect of surfactants on spectra using several nozzle types; effect of adjuvants on spectra of commercial pesticide formulations in combination with several adjuvants; factors affecting spectra when spraying Bt; effect of Bivert on spectra; effect of temperature on spectra for formulations, spectra of rainfall simulator, etc. References: Chapple et al. (1992,1993,1995), Downer et al. (1993,1995)

Drift and Targeting

Pesticide drift studies have traditionally used a variety of collectors. Associated protocols on drift and eco-toxicological effects are being developed in conjunction with orchard drift experiments with collaborators in USDA. A wind tunnel capture efficiency model is being used to develop droplet capture efficiency data on target (plant) and non-target species (windbreaks).
References: Downer et al. (1996) ,Hall and Fox (1996), Reed et al. (1993)

Worker Exposure Studies

Health risks to pesticide applicators are being scrutinized more closely than ever before. Although the available data from epidemiological studies concerning pesticide use and certain associated disorders are practically non-existent, federal and state agencies are mandating this research be initiated Current worker exposure studies revolve around (1) a US-EPA grant to LPCAT on validating passive dosimeters, and (2) a NIOSH grant on "Risks to Farm Families" to OSU's Department of Preventive Medicine, with LPCAT as principle collaborator on the chemical exposure risk phase. Numerous grant inquiries are underway involving neuro-behavioral responses of workers, neural network modelling of toxins and the PI's involvement in developing an American Chemical Society symposium on pesticide safety (in '97). Pesticide risk mitigation related to mixtures of pesticides. Insecticides, herbicides, fungicides, adjuvants, and fertilizers may be combined in a single spray application. Testing individual pesticides is not relevant to human health risk assessment because pesticides are not encountered as isolated compounds. References: Reed et al. (1990b), Kirchner et al. (1996a,b), Wolf et al. (1997)

Pesticide Risk Benefit Analyses

A pesticide cost-benefit assessment model was delivered to all US State Pesticide Coordinators in 1995. Analyzing risks and benefits in a useful assessment/prediction scheme will require additional information on actual environmental hazards which remains a major effort at LPCAT. Pesticide policy issues (PI focus) are critical if pest control agents are to continue as effective tools of world agriculture. References: Hall and Lemon (1990), Lemon et al. (1992), Hall (1996)

Modelling

The LPCAT pesticide dose simulator (PDS) model was developed to simulate diamond back moth larvae feeding on Bt (*Bacillus thuringiensis*) treated cabbage leaves. It provides a fundamental capability for examining the effects of deposit structure on efficacy. Further development has increased the generality of the model for examining different formulations and AIs. The LPCAT evaporation model combined with other physic-chemical measurements allows a greater level of inquiry into pesticide characteristics, and optimizing toxin presentation to target pests. References: Hall et al. (1995)

FABE RESEARCH PROJECTS

Effect of drift retardant chemicals on spray drift, droplet size and spray pattern

Specific objectives of this study were to determine the effects of various drift retardant chemicals (Direct, Driftgard, Formula 358, Nalco-trol, and Target) on droplet size, spray pattern, and spray drift reduction. The results of this study indicated that, at recommended rates, Nalco-trol provided the largest increase in volume median diameters of the sprays followed by Direct, Target, Driftgard, and Formula 358. In general all drift retardants created patterns with greater volume toward the center than that of water only. Cumulative deposits beyond 1.6 ft downwind increased for all drift retardants when the wind velocity was increased from 4.5 to 9 mile/h. In general, the effectiveness of drift retardant mixtures for minimizing spray deposit distances was closely related to droplet size increase. References: Ozkan et al. (1993a,b, 1994)

Effect of nozzle wear on spray pattern and droplet size

The effects of nozzle wear on spray patterns delivered by fan pattern nozzles made from different materials were investigated. An automated computerized weighing system was used to rapidly evaluate the spray deposit distribution. The results indicate that there was some difference between the spray deposit distributions of new and worn fan nozzles. The width of the spray pattern remained nearly constant but the worn nozzles delivered greater volumes of liquid in the centers of the patterns. The effects of nozzle wear on droplet size spectrums delivered by fan pattern nozzles made from different materials were investigated. Flow rates of the nozzles tested were 0.2, 0.4, 0.6 and 0.8 gal/min, and the materials were brass, nylon, plastic, stainless steel and hardened stainless steel. Although the worn nozzles produced slightly larger $D_{V0.5}$ values, generally there was little difference in droplet size distributions between new and worn

nozzles with flow rates smaller than 0.6 gal/min. The difference, however, was greater for the nozzles with flow rates of 0.6 and 0.8 gal/min. A standard procedure for measuring nozzle wear was develop and approved by ASAE as Standard S471. References: Ozkan et al. (1991, 1992a,b), Ozkan and Reichard (1991,1993), Reichard (1991a,b), Reichard et al. (1991), Zhu et al. (1995a,b)

A survey on attitudes of applicators toward pesticide waste reduction

As part of the ongoing pesticide education programs in Ohio, a survey was conducted in eighteen counties to learn more about current pesticide application and disposal practices. The survey also provided information related to applicators' attitudes toward reducing pesticide waste. Survey results based on 1380 responses indicate over two-thirds of the respondents calibrate their sprayers at least once a year. Approximately 10% never calibrate. Over 90% of the respondents always rinsed empty pesticide containers. However, only 71% followed acceptable rinsing procedures. About 3% indicated they do not rinse containers at all. Burning was the number one method of pesticide container disposal used by applicators. Although over two-thirds of the applicators feel well-informed about pesticide container disposal practices, the number of improper disposal methods identified by the respondents indicate that educational programs are needed to help applicators choose the most environmentally sound disposal practice. In general, the pesticide applicators expressed a positive attitude toward reducing pesticide waste. References: Ozkan (1992b)

Subsurface injection of turfgrass insecticides

Surface application of insecticides on turfgrass for control of many subsurface grubs is not very efficient. It can be potentially hazardous to people, pets and other animals exposed to the insecticides. To reduce this danger, three injection systems were developed to place insecticides below the turf surface and into the main grub activity zone. Results indicate that insecticides can be successfully injected with little damage to the turf. Analyses of surface residues after injection of two common turfgrass insecticides showed significant reductions ranging from 38 percent to 95 percent over the amount remaining from spraying on the surface. Grub control using two of the three injection methods was equal to or better than that achieved with the conventional surface application method. A third injection method using a rolling point applicator was not evaluated for grub control because the preliminary data showed little dispersion of insecticide from the point of injection and a low probability of achieving effective control. References: Ozkan et al. (1990a,b)

Deposition efficiency of air-assisted, charged sprays in a wind tunnel

Small spray droplets which rely primarily on electrostatic and gravitational forces for transportation and deposition are highly susceptible to drift. Also, spray penetration into dense plant canopies is often inadequate. Spray deposits of air assisted charged sprays, with volume median diameter of 92 μm, were collected in a wind tunnel with wind velocities up to 11 mile/h. The results indicated that an air jet with 24.6 mile/h downward air velocity at the point spray was entrained, greatly increased the amount of spray deposited in the target area and also improved penetration of the spray

downward into the canopy and reduced drift. References:Almekinders et al. (1992,1993a,b), Khdair et al. (1994)

Computer simulation of spray drift from field sprayers

A computer program was used to determine the effects of several variables on drift distances of individual spray droplets. Variables were initial droplet size, velocity and height of discharge, wind velocity and turbulence intensity, relative humidity, and volatility of the liquid. Drift distances of water droplets as large as 200 μm diameter were influenced by initial droplet velocity and height of discharge. Experimental data from tests in a wind tunnel verified the accuracy of the computer program in predicting drift distances of water droplets. A computer program was developed to calculate mean drift distance for individual spray droplets. This program accepts input parameters, then interpolates among a data base of results from flow simulation trials to obtain drift distancd for the input conditions. References: Reichard (1992a,b), Reichard et al. (1994), Reichard and Zhu (1995), Zhu et al. (1994, 1995c)

An automated computerized spray pattern analysis system

Most of the patternators used currently to investigate nozzle spray pattern characteristics are of the manual type using collection cylinders. These patternators are susceptible to human error during recording and analyzing data. This process is also labor intensive and time consuming. Results of a survey conducted indicate that with manual patternators it takes an average of 35 minutes to collect and analyze pattern data for one nozzle. The automated single collection unit system described in this article provides a more efficient means of data collection and analysis. On an equivalent per cylinder basis, the time for data collection takes about 0.5 seconds. It also takes only about a minute to complete a test with this system. The automated system was found to be relatively accurate compared to manual systems. References: Ozkan and Ackerman (1992)

Use of shields to reduce drift

The effects of partially covering spray booms with six different mechanical shields on deposition distances of spray droplets were simulated by using a computational fluid dynamic software, Fluent®. The same shields were mounted in a wind tunnel and drift distances of uniform-sized droplets in a 13.4 mile/hr air stream were measured. Use of solid bluff-plate shields inevitably resulted in a low velocity zone immediately behind the shield or within the shielded area. As compared with conventional straight-down spraying, all shields simulated, except ones, reduced drift potential. The double foil shield was confirmed to be the best design for mechanical shields in this study. The optimal operating parameters of pneumatic shielded spraying, obtained by a multifactor analysis of variance, were jet velocity of 90 mile/h, jet flow rate of 3600 ft^3/min, and jet angle of 15 degrees. Mean deposition distances from simulation and experimental distances to centers of masses agreed well for only 2 of 6 mechanical shield designs tested. Effect of shield-induced vibration and improper size ratio of shields to the wind tunnel may be reasons for this inconsistency. References: Ozkan et al. (1997a,b), Tsay (1997)

Measuring mixing in an agrochemical sprayer tank

Effectiveness of hydraulic jet agitation systems of agricultural chemical sprayers were investigated by measuring the concentration of a kaolin clay/water mixture in the line to the boom. A surface scatter type turbidimeter was employed to evaluate the concentration of simulated wettable powder pesticides during an application. An agitation index, called "AGEF", was defined to help evaluate the effectiveness of each agitation system separately regardless of tank size and shape. AGEF was based on three measured mixing criteria: particle deposit remaining on bottom of tank following application, the coefficient of variation of mixture concentration in the line to the boom, and ratio of maximum deviation of mixture concentration at the tank outlet to the mean concentration measured during the application. Experiments were conducted on several sprayer tanks of different capacities and agitator type. The results showed AGEF was sensitive enough to enable reasonable comparisons and this method can be used to standardize minimum requirements of a hydraulic jet agitation system. System pressure was the most important factor affecting agitation effectiveness through its direct influence on jet velocity. Single-phase solutions to Fluent computer models agreed well with these results. However, solving three dimensional, turbulent, multiphase flows (Eulerian granular model) was not feasible using personal computers because computation times would be several months. References: Ackerman et al. (1993), Ucar (1997).

Lag times and uniformity of inline injection of spray materials

Injection sprayers can eliminate some problems associated with conventional sprayers, however, injection sprayers have inherent problems of lag time and mixture uniformity at nozzles. A turntable sampling system was designed to measure uniformity of the mixture in the spray boom and the lag time required for the desired mixture concentration to be sprayed from nozzles at a range of boom lengths. A computer controlled system allowed the operator to collect samples easily at any nozzle while the simulated sprayer underwent accelerations or decelerations. Three water-soluble and one non-water-soluble liquids (water, Prime Oil, Prime Oil II and Silicon Oil) with viscosities that ranged from 0.9 to 97.7 centipoise were used as the simulated pesticides. Uniformity of the mixtures with the simulated pesticides in two boom sizes (3/8 and 3/4 in. diameters) and uniformity across the spray patterns of nozzles at different positions on the boom were investigated. Lag times to the expected rates of application were also measured. Viscosity of water-soluble or non-water-soluble liquid slightly influenced the mean flow rate from the metering pump, but did not influence the lag time. Simulated pesticides with the highest viscosities were very difficult to mix with water, and it was necessary to use a spiral mixer. Increasing the number of active nozzles on the spray boom reduced the variation of the mixture uniformity in the spray boom. Lag time to the desired rate of application at the nozzle at the end of the boom was greatly reduced by reducing the boom diameter, but this lag time was not reduced substantially by reducing the number of active nozzles on the boom. References: Zhu, et al. (1998a,b,c)

USDA-ARS ATRU RESEARCH PROJECTS

Orchard air jet velocity profiles and model

The mathematical model for ideal, plane jets was modified to include the effect of radial expansion as the air jet moved away from a circular jet outlet. This model was found to have an improved fit to the maximum velocity across a jet as distance from the jet increased, as compared to the plane jet model previously used. Jet profiles were measured for two axial fan sprayers and agreed well with model predictions using the radial jet model. Centerline velocities in an air jet produced by a cross-flow fan sprayer were measured and agreed well with predicted values computed using a plane jet model. For jets that have equal air power at the jet outlet, models for ideal jets predict that axial jet velocities from jets with greater air volume and lower maximum air velocities will decrease much less as distance from the outlet increases, compared to jets with high velocity and lower air volume. Measured air velocities for sprayers passing an array of hot-film anemometers on towers in the open and in apple trees found that maximum jet velocities produced by moving sprayers was much less than velocities measured for the same jets when stationary. A model of the deflection of an air jet by travel speed or cross wind was developed. Jet deflection and velocity profiles predicted by for the deflected jet were similar to velocities measured for a model jet operated in a wind tunnel. References: Brazee et al. (1981), Fox et al. (1985, 1992b)

Drift from orchard sprayers

Ground-level and airborne spray samples were collected downwind of apple orchard in a series of drift experiments over the past 8 years. Convention axial fan and air-curtain/cross-flow fan sprayers were used to successively spray the downwind, edge row of trees each year. With an available crew of about 12 people, about 5 replications could be conducted in one day. Due to row planting directions, measurement of drift is only possible when the wind is approximately perpendicular to the row direction. In our experience, only about 1 to 2 days per month had a suitable wind direction for drift experiments. We usually set up the major collection and meteorological towers for about 2 months per year, set up temporary collectors and prepared for drift trials about 4 to 5 times per year, and actually sprayed about 2 days per year. Fluorescent tracers were used. Rigid plastic sheets and, later, plastic tape was used to collect ground deposits. Airborne spray was collected on passive collectors such as string, plastic tape and, recently on nylon screen. High volume air samplers were also as an active collector of airborne spray. Different fluorescent tracers were used in each sprayer and collectors were changed after both sprayer completed each pass. A total of about 50 spray passes have been made during the 7 years when drift experiments were conducted, thus a range of wind conditions have been encountered. Three orchard sites have been used to provide a range of canopy sizes and shapes. References: Fox et al. (1990a,b, 1991b, 1993a,b,c, 1994b, 1997), Fox (1993), Reichard et al. (1992a,b, 1994), Derksen and Breth (1994), Reichard and Zhu (1995,1996), Derksen and Gray (1995), Perez et al. (1995), Coffman and Derksen (1997)

Greenhouse spraying

Electron beam analysis (EBA) was used to measure chlorothalonil smoke particles on artificial target surfaces in greenhouses. Particles averaging less than 3.0 μm in diameter and as small as 0.4 μm were found to vary significantly in number with location within a poinsettia canopy and with distance from the source of the smoke.

Particles did not vary significantly in size either within the canopy or with distance from the source. No measurable residue was found when the greenhouse was not tightly sealed. EBA proved to be a viable method of investigating fungicide smoke deposition and can provide precise information about the environmental fate of pesticides related to application technology. References: Tappan et al. (1995), Derksen and Sanderson (1995), Obendorf et al. (1995)

Spraying of nursery crops

Spray penetration and off-target spray drift from a conventional, air-assist, axial fan sprayer and a high-clearance, boom-type sprayer were investigated in honey locust or canadian hemlock located in two different production nurseries. Another study in a production nursery compared spray coverage on sheared red maple from an axial fan sprayer with a cross-flow fan sprayer. Aqueous tracer solutions of either $Ca(NO_3)_2$ foliar fertilizer, $Cu(OH)_2$ fungicide, or food coloring were used in the experiments. Spray distribution and drift were assessed via residues collected on foliage, electron microscope stubs, vertical and ground-level profile tapes, clamped leaves, and high-volume air samplers. Electron beam analysis (EBA) was used to assay residues on stubs, leaves and needles placed and/or collected at several locations and elevations in the canopy. Profile-tape samples were evaluated with a laboratory spray deposit analyzer using a conductivity detector. Spray coverage for the hemlock and locust treatments was incomplete throughout either canopy as assessed by either method. Experimental results indicated that ground-level spray deposits and airborne drift varied with the spray method used. Spray deposits on red maples (about 3.5 m tall) were measured using blue food coloring and $Cu(OH)_2$ fungicide. Colorimetry and EBA were used to measure deposits on leaves clamped at 12 locations (3 elevations, 4 quadrants) in each of three trees. The cross-flow fan sprayer produced more uniform distributions throughout the tree, but the axial-fan sprayer produced greater deposits at almost all locations than the cross-flow fan sprayer. References: Krause et al. (1997), Zhu et al. (1997b)

Effectiveness of low turbo teejet and TurboDrop nozzles in drift reduction

Small-to-medium size droplets are desirable when applying insecticides and fungicides because they provide better penetration into the canopy and better coverage. However, small droplets can drift long distances. Almost all major agricultural nozzle manufacturers have recently introduced "low-drift" nozzles which claim to be effective in reducing spray drift. The objective of this study was to determine effectiveness of two "low-drift" nozzles (Turbo TeeJet® and TurboDrop®) in reducing drift. This was accomplished by measuring droplet sizes, and deposition distances of droplets in a wind tunnel (11 mile/h) using the low-drift nozzles and comparing the data from these measurements with those obtained from a standard flat-fan nozzle. The low-drift nozzles produced fewer drift prone droplets and less downwind deposits than the standard flat-fan nozzle (XR). Droplet size measurements taken along the long axis of the spray patterns showed less variation in droplet size for the XR and Turbo TeeJet (TT) nozzles than for the TurboDrop (TD) nozzles. The TD nozzles produced lower downwind deposits than TT nozzles operated at similar pressures (40 psi); however, a larger orifice TT nozzle operated at a lower pressure (25 psi) performed similar to the TD nozzle operated at 40 psi. Plugging the air intake hole on the TurboDrop nozzle

increased nozzle output, decreased VMD, and slightly increased the percent of spray volume in drift prone droplets and downwind deposits. References: Derksen et al. (1997)

Shear effects on drift retardants

Some research has indicated that certain drift retardants may degrade due to the shearing action of recirculation through a agricultural sprayer pump. A laboratory system was developed to simulate shear on spray mixtures of water and drift retardants due to recirculation of mixtures in sprayer tanks. Three drift retardants were evaluated in both a Myers A36 orchard, airblast sprayer and the laboratory system. Droplet size distributions of sprayed samples from the sprayer and the laboratory system were measured with an Aerometric Phase/Doppler Particle Analyzer. Droplet size distributions of sprayed samples with drift retardants sheared with the laboratory system had similar trends to those of samples sheared with the airblast sprayer as the number of recirculations increased. In a further study, ten polymers which are primary active ingredients in commercial drift retardants were tested. Samples of the solutions were taken after 0, 1.0, 2.3, 3.9, 6.4, and 11.4 passes through a centrifugal pump system. Apparent extensional viscosity (AEV) and screen factor (SF) were measured for all samples. After being sheared by more than 4 passes through the pump, both non-ionic and anionic polymer-solutions at 100 ppm did not increase $D_{V.5}$ much over values for water alone. Both apparent extensional viscosity ($R^2 = 0.8$) and screen factor ($R^2 = 0.7$) were well correlated with spray $D_{V.5.}$. These results show that some drift retardants may fail to maintain their ability to increase spray drop sizes after they have bypassed several times in an agricultural sprayer. References: Fox et al. (1996), Reichard and Zhu (1996), Reichard et al. (1996), Zhu et al. (1997a)

High speed image capture

High speed movies (6000 frames/s) were made of droplets impacting on leaf surfaces. Many plant leaves have a surface wax structure that reflects spray droplets on initial impact. The movies enabled observing the number of droplets that were reflected and the height of rebound, but measurements of rebound characteristics were not easy to make. A high speed video system was developed to capture several video frames in succession. The video speed was only from 15 to 150 fields/s, however, by using high speed strobe lighting as a shutter, interesting images of droplet rebound paths could be obtained. The video system, used in conjunction with two different mono-disperse droplet generators, quantified droplet impaction and any consequent reflection. Three techniques were used for assessing the deformation at impaction of a single droplet on an artificial surface, and reflection of both single droplets and droplets in a spray cloud, from a variety of plant surfaces. Determination of droplet in-flight diameter, dimensions of impacting droplets, droplet velocity prior to and immediately after impaction, and reflection height and number were all possible depending upon the technique selected. References: Reichard et al. (1986), Fox et al. (1992a)

Droplet impaction and reflection

Droplet reflection depends, to some extent, on the speed of the impacting droplet and droplet size, but the main factor in determining reflection is the micro-structure of the

leaf surface. Some plants, such as cabbage, wheat, and rice reflect nearly all spray droplets that impact on the surface. Large droplets (500 μm diameter) tend to be reflected more than small droplets (100 μm diameter), but we have recorded water droplets less than 70 μm that reflect from cabbage leaves. Typical droplets impacting on reflective leaves remain on the leaf surface less than 1 ms. While the droplet is on the leaf, it greatly increases its surface area by distorting into a pseudo-torus shape, then reduces surface area by drawing back into a spherical shape before springing from the leaf surface. Some adjuvants, such as surfactants tend to reduce reflection. In fact, if high concentration of some surfactants are used, refection can be eliminated. Most surfactants must move to the liquid interface to become active. With the large changes in droplet surface area during the impaction process, the diffusion rate of typical surfactants is too slow to reduce surface tension in the one millisecond available. References: Bukovac and Reichard (1990), Reichard (1990), Bukovac et al. (1993,1995), Brazee et al. (1994,1997), Reichard et al. (1998)

Dynamic surface tension

Several physical properties of the droplet liquid, such as surface tension and extensional viscosity, may affect reflective potential of spray droplet from plant leaves. Equilibrium surface tension, a commonly measured liquid property, is not a reliable indicator of reflection tendency. However, dynamic surface tension has been found to be strongly related to droplet reflection. An oscillating jet method was developed enabling measurement of dynamic surface tension at a range of short surface ages, even as short as 1 ms. Bohr's equation and Bechtel's inverse method were used to calculate surface tension from measurements of the jet waveforms. Some surfactants are unable to reduce surface tension rapidly at short air-liquid interface ages typical of droplet impaction processes. Hence, they may be unable to effectively limit reflection and improve retention. A thin-film diffusion model was developed which can be used to calculate dynamic surface tension at a range of surface ages, given liquid properties, surfactant diffusivity, apparent interfacial film thickness, and surfactant concentration. Correlating measured dynamic surface tension data with the diffusion model provides estimates of apparent film thickness and diffusion of surfactant/water mixtures. These activity properties are useful in understanding surfactant effects on high shear rate physical processes such as droplet atomization and leaf-surface impact, where short surface ages are critical. Most agricultural sprays are mixtures of materials, not true solutions, and as such their surface tensions change with surface age. Measuring surface tensions at short surface times may also be valuable in predicting droplet size spectra from atomization processes, because these processes are usually completed in less than 3 ms. Brazee et al. (1991), Bechtel et al. (1995), Reichard et al. (1997)

Image analysis

Computer imaging equipment and image processing software has been used by ATRU staff to measure quality aspects of spray applications. Measurements of feature density, size, and target coverage have been used to compare the performance of different application techniques. Evaluations have been made using artificial targets such as oil and water sensitive paper and natural targets such as plant leaves. Different

image processing algorithms have been used to evaluate images depending on the target, tracer, and droplet size characteristics. Morphological image processing techniques proved most useful when evaluating parameters of features produced by water-soluble tracers. Recent acquisition of an epi-fluorescence microscope with a high intensity, UV light source will improve our ability to evaluate coverage produced by different application methodologies through use of fluorescent tracers and other materials that naturally fluoresce. This equipment will also permit study of the interaction between the spray quality and pest damage on leave surfaces as well as the effect of spray formulations on plant material. Natural fluorescence of plant pathogens and leaf structures will also be studied to determine if these may aid in evaluating the application process, pest management, or crop production. References: Salyani and Fox (1994,1997), Derksen and Jiang (1995), Jiang and Derksen (1995)

Japanese beetle

Adult and immature Japanese beetles (JB) are serious pests of turfgrass, flowers, fruit crops and ornamentals. The larvae, white grubs, develop in the soil in the grass root zone. Control of these grubs is difficult because a significant portion of pesticides applied to the turf can become bound by organic matter in the thatch and never reach the feeding sites. Several entomopathogenic bacteria, fungi, and nematodes have been tested for grub control. Although several commercial biological products are available, results of their use has been inconsistent. A survey of northern Ohio golf course turf found about 20% of the sites had detectable entomopathogenic nematode (EN) populations. However, only about 15% of these EN provided more than 75% control of grubs in laboratory tests. Selected isolates of Ohio EN performed as well in field tests as did commercially available nematodes. Improved application methods may enhance EN control of JB larvae. In addition, EN performance may be increased when used with other control agents. An insecticide, imidacloprid, was shown not only to be non-toxic to EN, but to have a synergistic effect against masked chafer and JB larvae when both control agents were used simultaneously. In a new approach to pathogen application, autodissemination, beetles are lured to a trap where they become coated with a fungal pathogen and subsequently transfer the fungus to larval feeding sites. References: Mannion et al. (1996), Grundler and Klein (1997), Klein and Moyseenko (1997)

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